AD NUMBER

AD822715

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 16 OCT 1967. Other requests shall be referred to Air Force Technical Applications Center, Washington, DC 20330.

AUTHORITY

USAF ltr, 25 Jan 1972

822715

LARGE-ARRAY SIGNAL AND NOISE ANALYSIS

Special Scientific Report No. 3

SUBARRAY PROCESSING

Prepared by

Terence W. Harley

Frank H. Binder, Program Manager

TEXAS INSTRUMENTS INCORPORATED
Science Services Division
P.O. Box 5621
Dallas, Texas 75222

Contract No. AF 33(657)-16678

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D.C. 20333

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
ARPA Order No. 599
AFTAC Project No. VT/6707

16 October 1967

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTD)

SECTION I

SUMMARY

A theoretical Wiener multichannel filter was designed and applied to all operating subarrays for 14 noise samples and three signals. The filter system chosen had a disk signal model (11 km/sec to infinite velocity) and a noise annulus (2 to 6 km/sec) and exhibited good wavenumber response to 0.2 cps.

Preliminary analysis showed that it was necessary to equalize the noise at the low-frequency peak (0.2 to 0.3 cps) prior to processing to obtain consistent noise rejection at low frequency. Because of the peaked spectrum, equalization could be accomplished by adjusting the 25 channels in a subarray to have the same RMS noise level (i.e., 1-point equalization).

Two measured-noise Wiener filters were designed using an infinite-velocity signal model (with 30-percent gain fluctuation added). Their noise rejection was about 2 db better than the theoretical system over most of the 0- to 5-cps band.

The theoretical Wiener filter performed about as well as the maximum-likelihood filter that had been applied to a noise sample not used in its filter design. The measured-noise Wiener filter performed almost as well as the maximum-likelihood filter that had been applied to the noise sample from which it was designed.

Within a subarray, the noise at LASA was more than 99-percent predictable at the microseismic peak (0.2 to 0.3 cps). At 1.0 cps, the noise was still 65-percent predictable; but above 2.0 cps, it was essentially unpredictable. These results are similar to those at TFO and WMO but signficantly lower than at CPO.

The absolute noise level on seismometer 21 of subarray C2 (which was close to the average LASA noise level) was between 0 and 6 db higher than that at TFO in the 0- to 1.5-cps band. However, variations in noise level larger than 6 db were observed across LASA, so the comparison should be considered in terms of average noise levels only.

SECTION II

INTRODUCTION

This report describes the short-period noise and signal processing of LASA subarray data and discusses some characteristics of the noise field which were obtained by analyzing the data.

Fourteen noise samples and three signals were processed (Table II-I). Outputs were obtained from each subarray which had good data for each noise sample. All data were equalized on the basis of the 1.0-cps calibration information, antialias filtered, and resampled to 0.1 sec prior to processing.

Table II-I

NOISE SAMPLES PROCESSED

Noise Sample	Type	Date	Time (GMT)	Subarrays not Processed
1	Day Noise	10/29/65	21:01:02.6-21:06:48.5	D3, E1
2	Day Noise	11/4/65	00:42:00.0-00:48:00.0	C1, C2
3	Noise, Aleutian Event	11/10/65	04:02:56.9-04:08:40.8	B1, E2, F3
4	Night Noise	11/13/65	02:05:00.0-02:11:00.0	A0, C2, F3
5	Night Noise	11/25/65	01:00:00.0-01:05:00.0	
6	Night Noise	12/1/65	02:13:00.0-02:19:00.0	A0, F3
7	Night Noise	12/4/65	03:07:00.0-03:12:00.0	F3
8	Day Noise	12/21/65	08:41:00.0-08:46:00.0	D1
9	Night Noise	1/22/66	06:57:00.0-07:05:00.0	F1
10	Noise, Greece Event	2/5/66	03:02:55.4-03:11:06.3	F1
11	Day Noise	4/8/66	05:18:09.3-05:26:09.0	B1, C1
12	Noise, Panama Event	4/15/66	06:44:08.1-06:52:08.0	B1, F3, F4
13	Day Noise	4/29/66	09:26:17.9-09:31:06.8	F1
14	Day Noise	3/25/66	04:26:12.8-04:34:12.7	B4

SECTION III

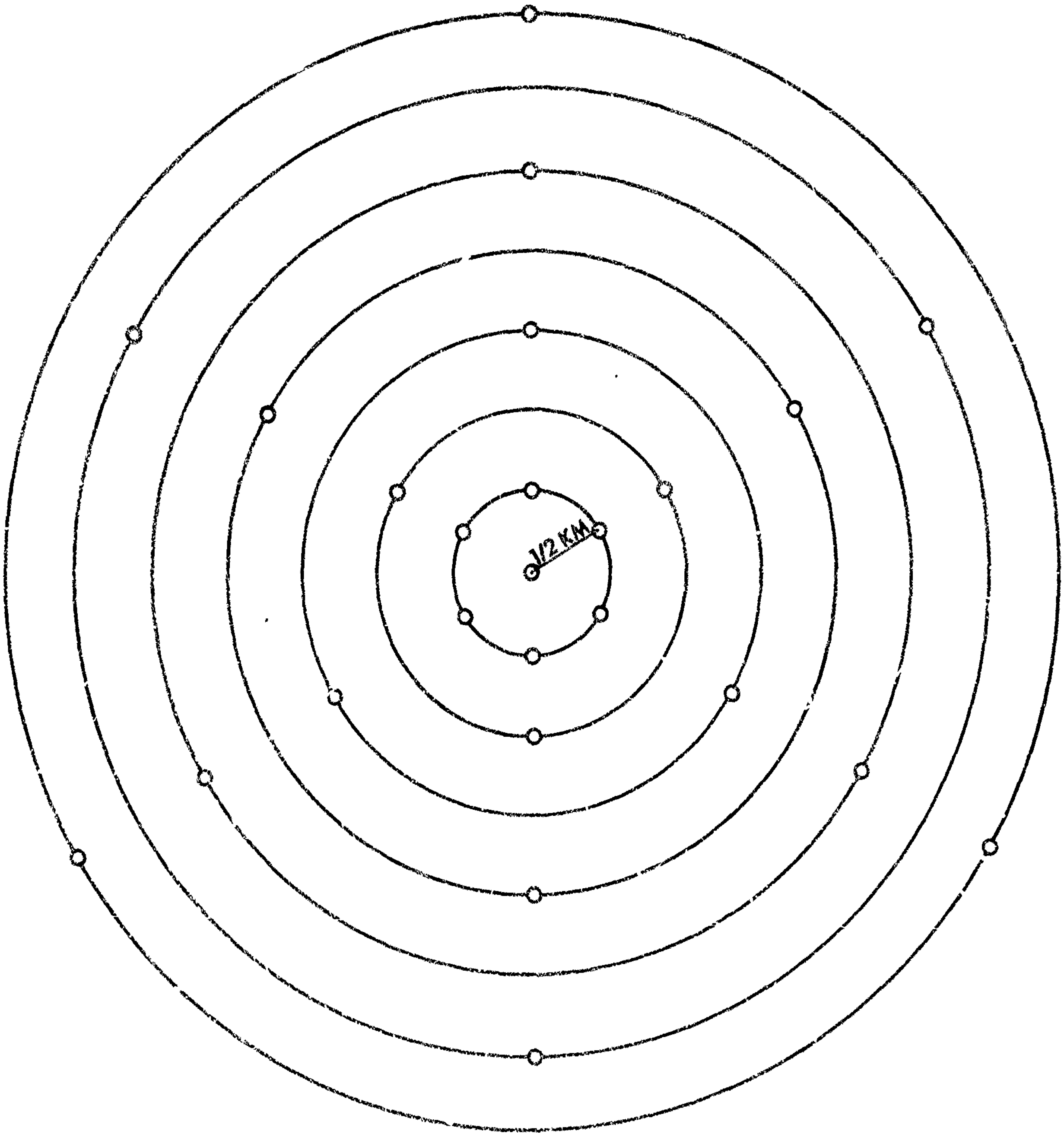
SUBARRAY PROCESSOR DESIGN

The multichannel filter chosen to process the subarray data was a 35-point (3.4 sec), 8-channel, ring-stacked system designed from theoretical correlations. A disk signal model of 11 km/sec to infinite velocity and an annular noise model of 2 to 6 km/sec were used. The signal-to-noise ratio was 4:1, and 1.0-percent spatially random noise was added for design stability.

This particular system was chosen because

- Previous experience indicated systems with these design parameters had satisfactory wavenumber responses
- It was necessary to preserve high-velocity data for large-ar y processing.
- At the time it was designed, little knowledge of the subarray noise field velocity structure existed, so a wide low-velocity band was used for the noise model
- The system could be used for both "long" and "short" subarrays (Figure III-1)
- The cost and time savings over measured-noise systems were deemed worth some loss in noise-rejection capabilities

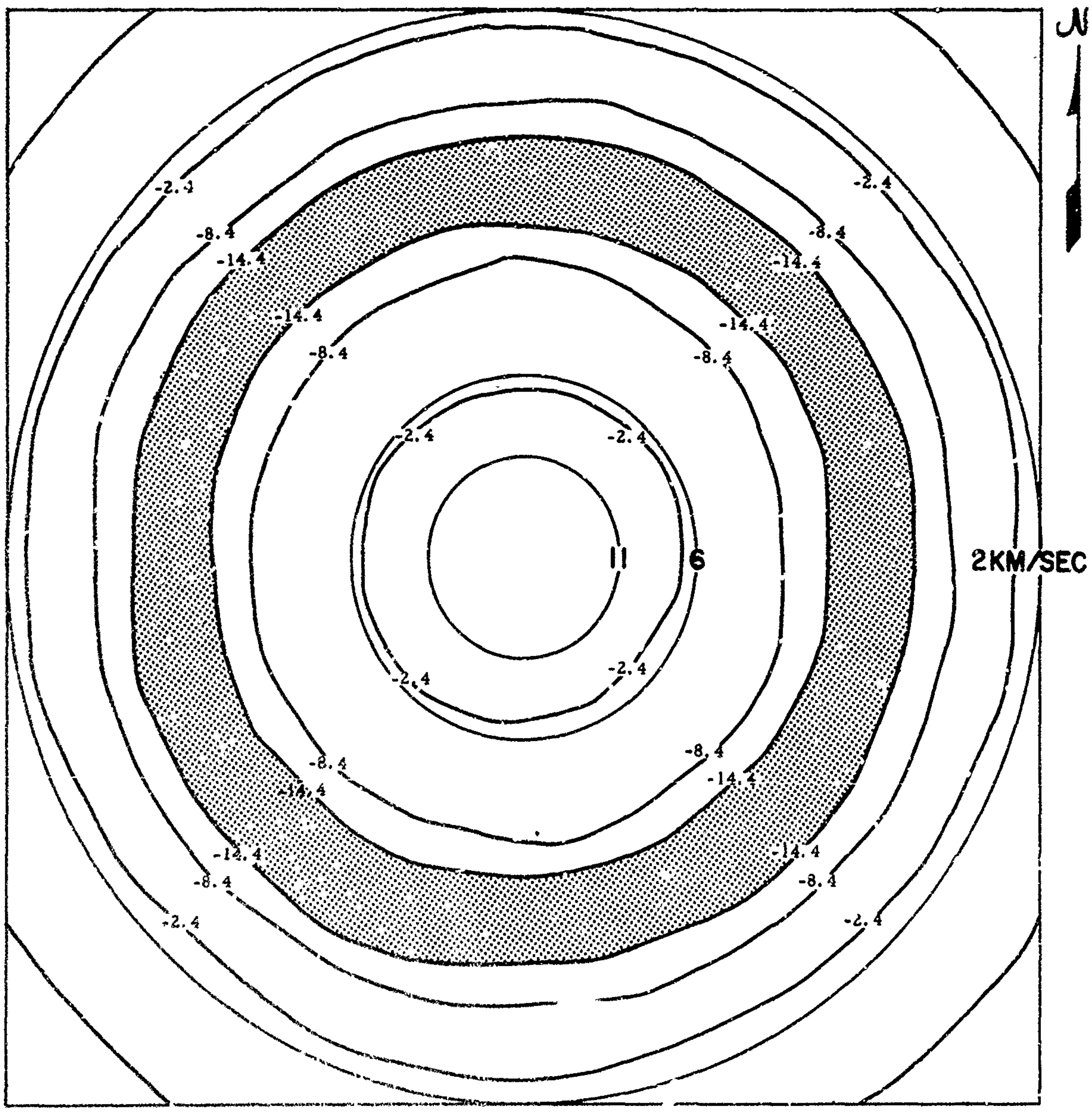
Figure III-2 through III-6 show the wavenumber response of the system at 0.2, 0.3, 0.5, 1.0, and 2.0 cps, respectively. Signal attenuation was less than 2 db at all frequencies. Noise rejection was good over the 2- to 6-km/sec velocity range, with maximum rejection occurring between 3- and 4-km/sec for all frequencies. Figure III-7 shows that the system's random-noise response was about -8 to -10 db above 1.3 cps (as compared with -14 db for a straight sum).



LONG SUBARRAY HAS SEISMOMETER ON OUTER RING
FOR NORTHERN ARM

SHORT SUBARRAY DOES NOT HAVE SEISMOMETER ON OUTER RING
FOR NORTHERN ARM

Figure III-1. LASA Subarray Geometry



<-14.4

Figure III-2. Response of Theoretical MCF at 0.2 cps

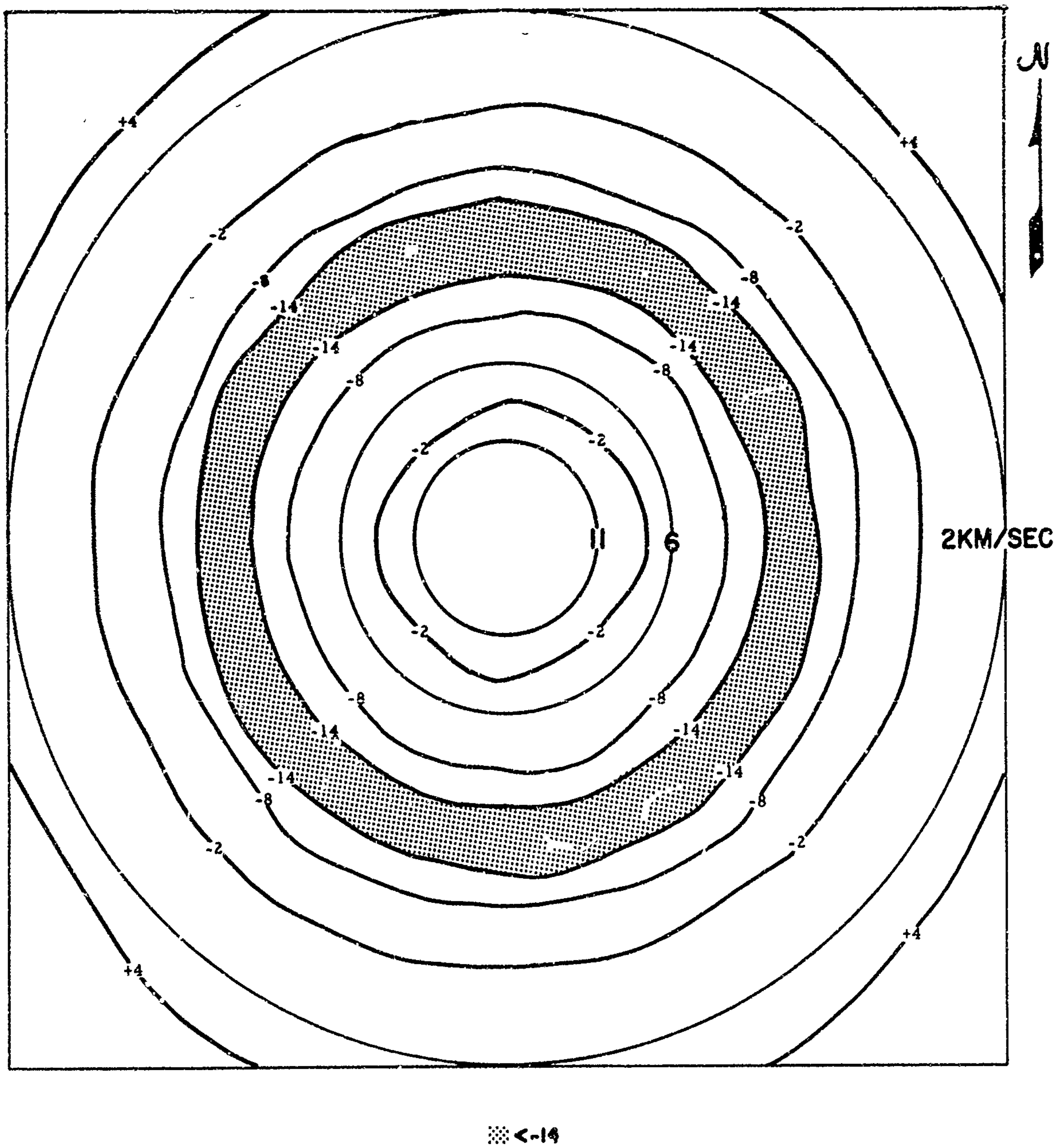


Figure III-3. Response of Theoretical MCF at 0.3 cps

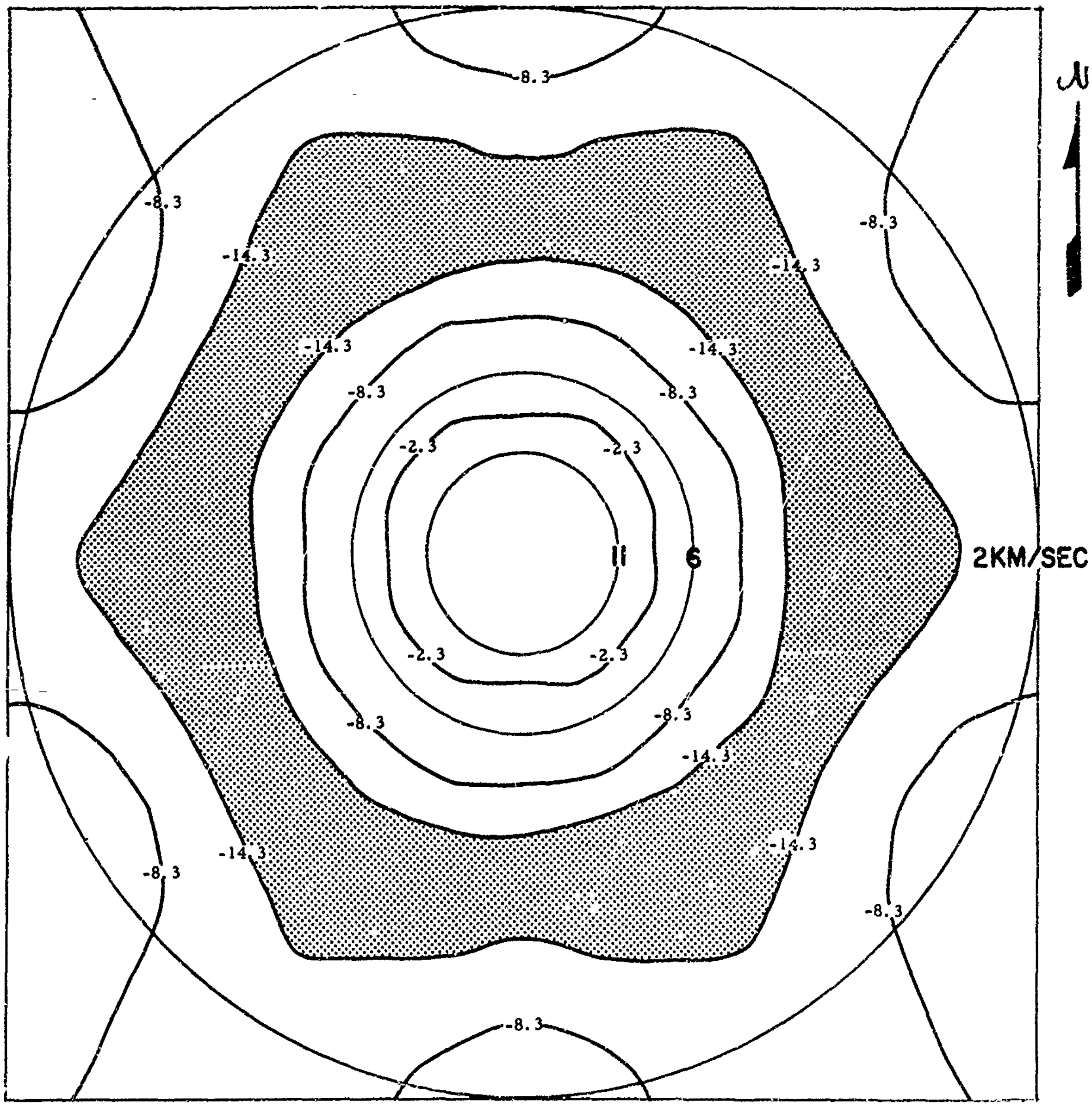


Figure III-4. Response of Theoretical MCF at 0.5 cps

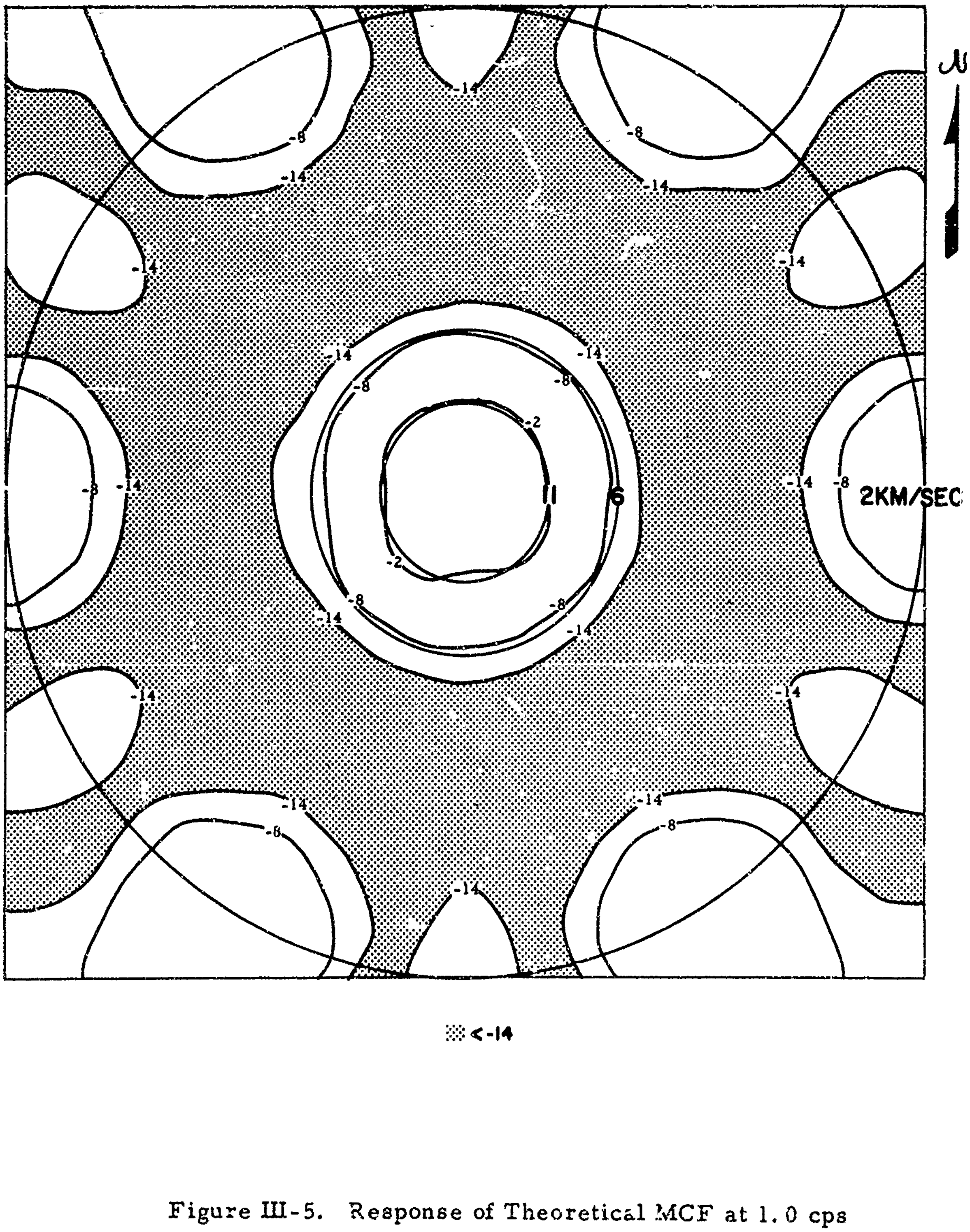


Figure III-5. Response of Theoretical MCF at 1.0 cps

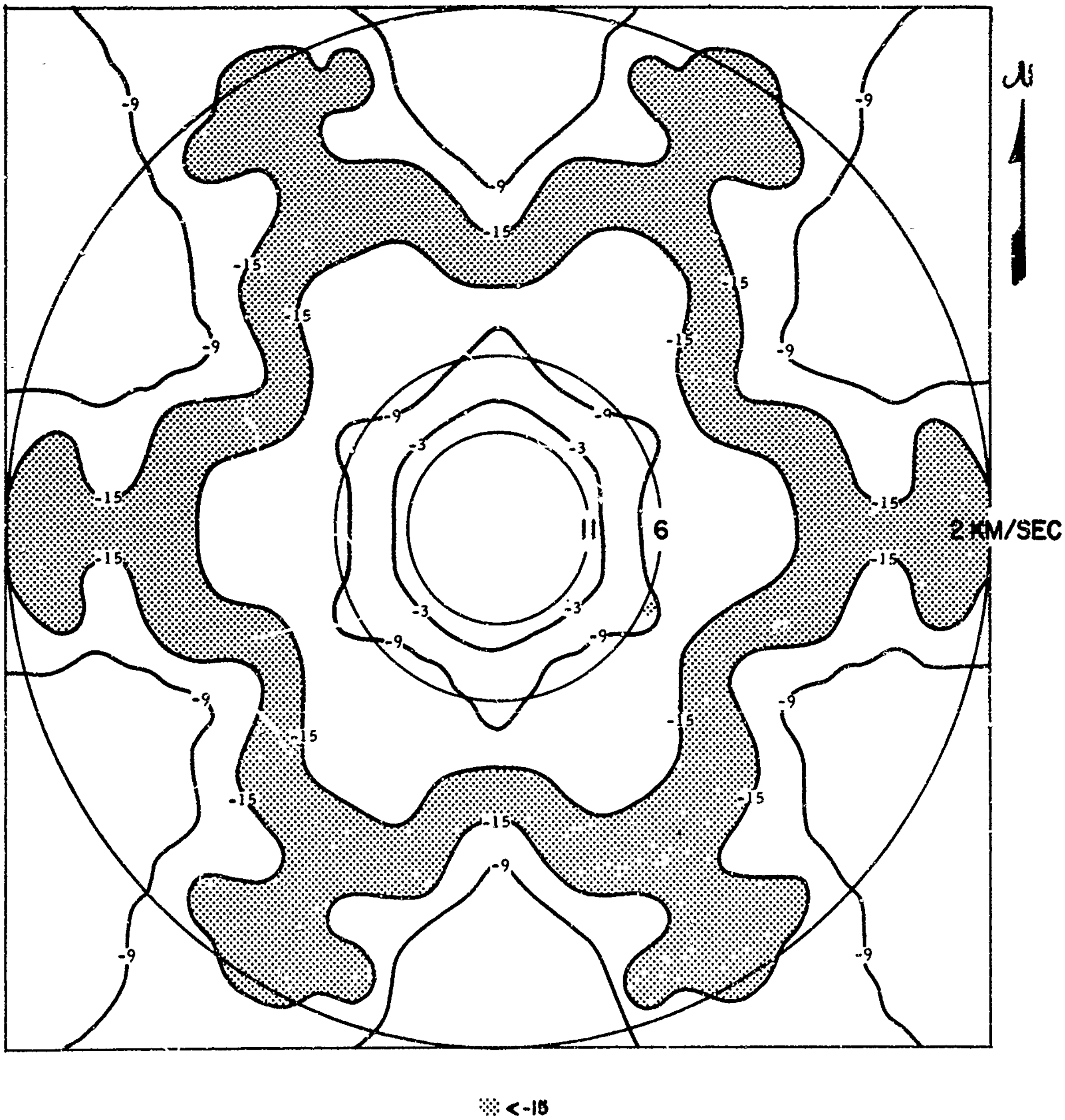


Figure III-6. Response of Theoretical MCF at 2.0 cps

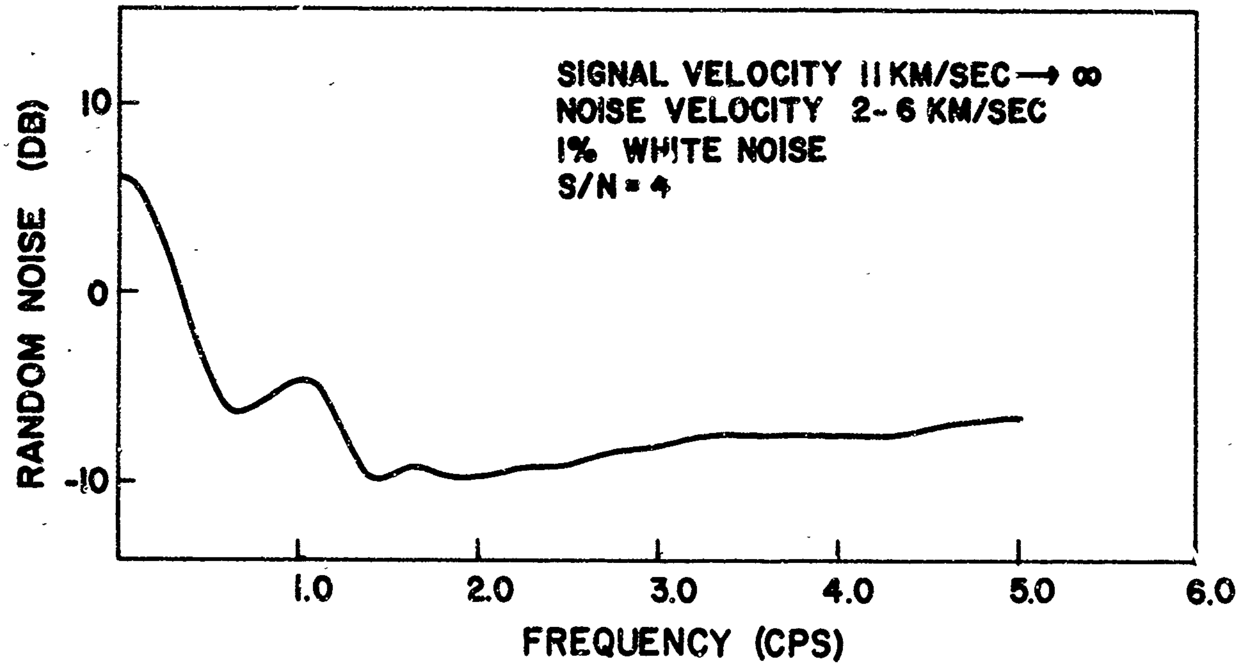


Figure III-7. Randon-Noise Response of Theoretical MCF

SECTION IV

PREEQUALIZATION OF NOISE DATA

The 25 March 1966 noise sample (14) was used to check the performance of the system. Twelve subarrays were processed (A through D rings), and spectral ratios of the noise out of the system to the noise on seismometer 21 were computed.

Considerable variation from subarray to subarray was observed, especially at low frequencies; in some cases, a ratio greater than unity was obtained. This result suggested that there were significant gain inequalities at low frequency within a subarray, even though the data had been equalized at 1.0 cps from the calibration information. The data were equalized at low frequencies by computing the RMS noise level on each trace and adjusting all traces in the subarray to the same level. This technique was chosen because the noise power spectra were sharply peaked at low frequency and also because of its simplicity.

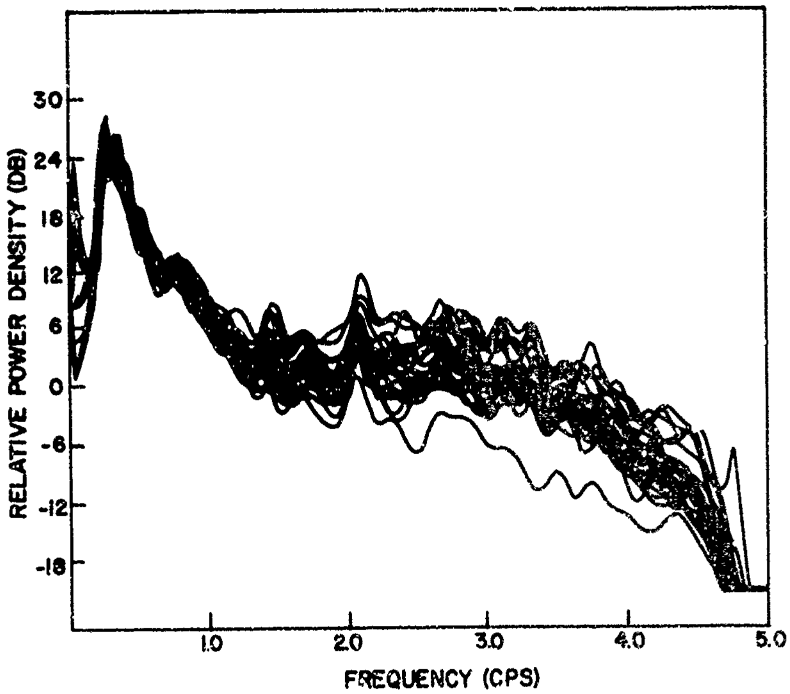


Figure IV-1. Power Spectra for the 25 Seismometers of Subarray D1 After RMS Equalization, 25 March 1966 Noise Sample

Equalization coefficients usually ranged from 0.6 to 1.5, although larger variations occasionally occurred. Figure IV-1 shows that the power spectra in subarray D-1 were well equalized at low frequencies (below 1.0 cps) using this method. The 12 subarrays then were reprocessed and the spectral ratios recomputed. Figure IV-2 compares the ratios before and after equalization for three subarrays and shows that the data were much more consistent after equalization. Thus, all noise data were preequalized on an RMS basis prior to application of the multichannel filter system.

To determine whether the preequalization had any adverse effects on signals (which have appreciable energy above 1.0 cps), two events were processed before and after preequalization. The signals were not appreciably affected.

The noise samples and three signals then were processed using the theoretical filter system. For the noise samples, power spectra of the processor output and seismometer 21 were computed for each subarray; and the ratio of the two was calculated. These data will be discussed in detail in Special Report No. 4.* The noise and signal subarray outputs were used in large-array processing (wavenumber-spectra analysis and multiple-coherence processing), discussed in other LASA reports.

*Texas Instruments Incorporated, 1967: Space and Time Variability of the LASA Noise Field, LASA Spec. Rpt. No. 4, Contract AF 33(657)-16678, to be published.

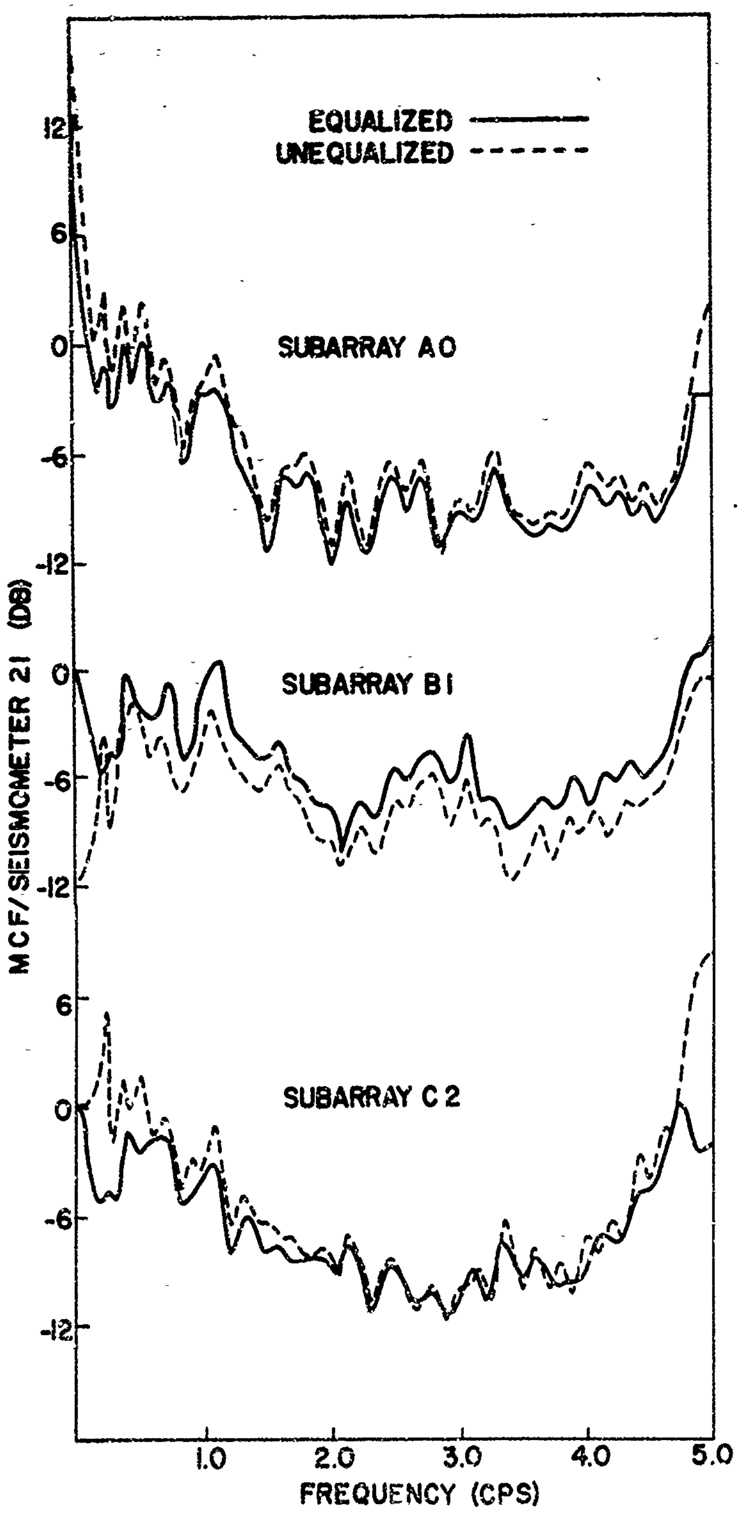


Figure IV-2. MCF/Seismometer 21 Spectral Ratios for Subarrays A0, B1, and C1 Before and After Equalization, 25 March 1966 Noise Sample

SECTION V

COMPARISON OF THE THEORETICAL AND MEASURED NOISE PROCESSORS

Two 8-channel, ring-stacked, measured-noise multichannel filters were designed so that the theoretical processor performance could be compared with that obtained for measured-noise data. Data from subarrays C2 and B1 for the 25 March 1966 8-min noise sample were used. For brevity, the C2 processor is called MNP1, and the B1 is called MNP2.

After preequalization, the data were approximately whitened, using a 1.0-sec deconvolution filter designed from the seismometer 21 output from each subarray, and applied to all channels. The signal model was taken as infinite velocity, and the autocorrelation function of the noise on seismometer 21 was used for the signal autocorrelation. Thirty-percent gain fluctuation was added to the signal autocorrelations to prevent the filter system from using gain inequalities to reject the noise. A signal-to-noise ratio of 4:1 and a filter length of 3.4 sec were used in the design.

Figures V-1 through V-5 show the wavenumber responses of the two filters at 0.2, 0.3, 0.5, 1.0, and 2.0 cps, respectively. Because of the array geometry, the wavenumber responses have three-fold symmetry. In general, the two systems have similar responses except that at 0.3 cps MNP1 has maximum rejection at about 3.0 km/sec, while MNP2 has maximum rejection at about 2.0 km/sec. In addition, at 0.5 cps, MNP1 rejection is isotropic at about 3.5 km/sec, while MNP2 rejection is directional at the same velocity. Figure V-6 shows that the random-noise response of the two systems was -10 to -11db above 2.0 cps (slightly better than the -8 to -10 db observed for the theoretical processor).

Figure V-7 compares the noise rejection obtained for the theoretical filter with that obtained for the measured-noise filters at the two subarrays. Comparing MNP1 and the theoretical processor, MNP1 had about 4 db less noise rejection at 0.2 cps, which implies the noise was propagating at velocities greater than 2.5 km/sec, even though the wavenumber response of MNP1 has a rejection zone at about 1.5 km/sec. Other analyses* gave no indication of a 1.5-km/sec noise mode at 0.2 cps. The reason for the seemingly anomalous behavior of MNP1 at 0.2 cps is unknown. At 0.3 and 0.5 cps, the two systems have about the same noise rejection, which is compatible with their wavenumber responses. At 1.0 cps, MNP1 gives about 2 db more rejection due to its better response at 5.5 to 6.0 km/sec. Between 2.0 and 4.0 cps, MNP1 has the better random-noise response. Note that both systems have more noise rejection than expected, which indicates that the seismometer 21 noise level was higher than average between 2.0 and 4.0 cps.

Comparing MNP2 and the theoretical processor, the two systems have about the same noise rejection at 0.2 cps. MNP2 has about the same wavenumber response as that of MNP1; but apparently, the noise-propagation velocity was different at the two subarrays, so the effect observed for MNP1 at 0.2 cps is not evident. At 0.3 cps, MNP2 has about 3 db more noise rejection. The MNP2 wavenumber response indicates a 2 km/sec noise mode for which the theoretical processor has poor response. Other studies* showed a low-velocity noise mode at 0.3 cps. At 0.5 and 1.0 cps, MNP2 has about 3 db better rejection, which is compatible with the wavenumber responses. Between 2.0 and 4.5 cps better random-noise response was obtained from MNP2.

*Texas Instruments Incorporated, 1967: Analysis of Subarray Wavenumber Spectra, LASA Spec. Rpt. No. 6, Contract AF 33(657)-16678, to be published.

In summary, the measured-noise processors were better than the theoretical processor at both subarrays, usually by about 2 to 3 db. However, at some low frequencies, little or no improvement was observed. Thus, the theoretical processor appears to be a good system.

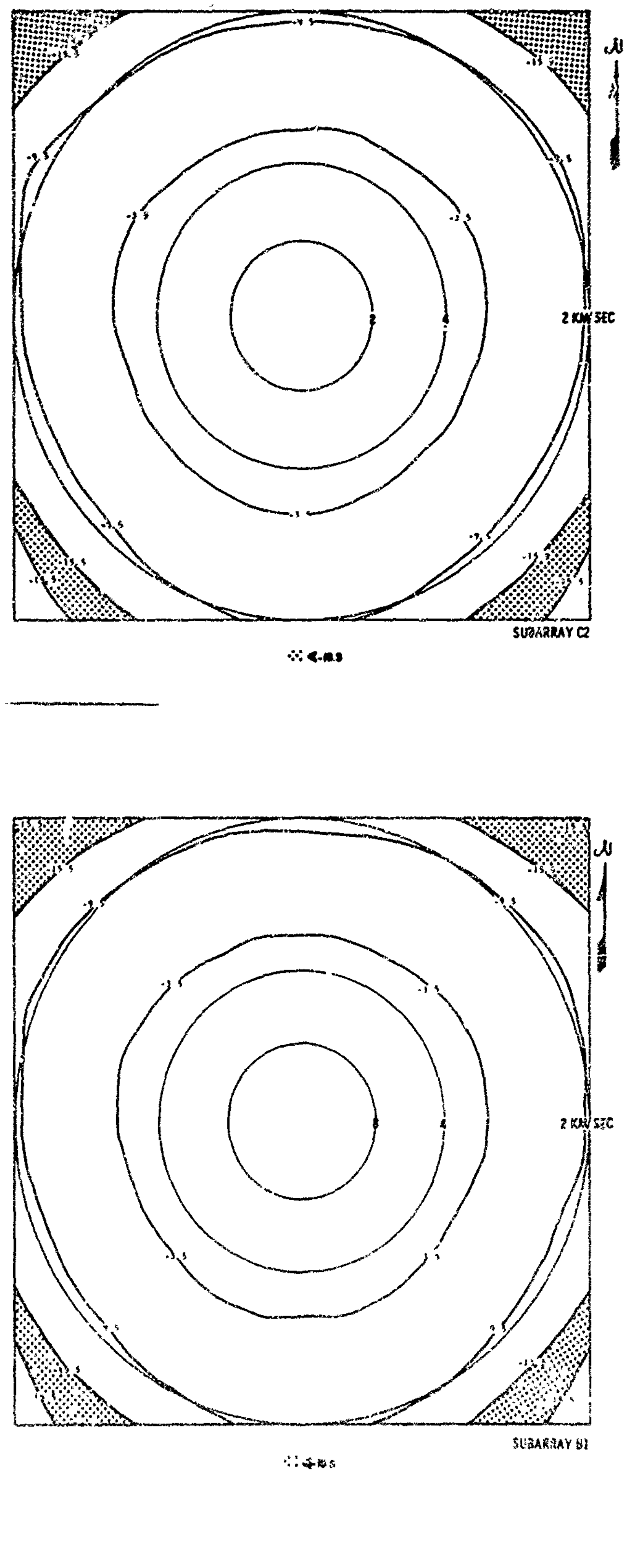


Figure V-1. Wavenumber Response of Measured-Noise Filter at 0.2 cps

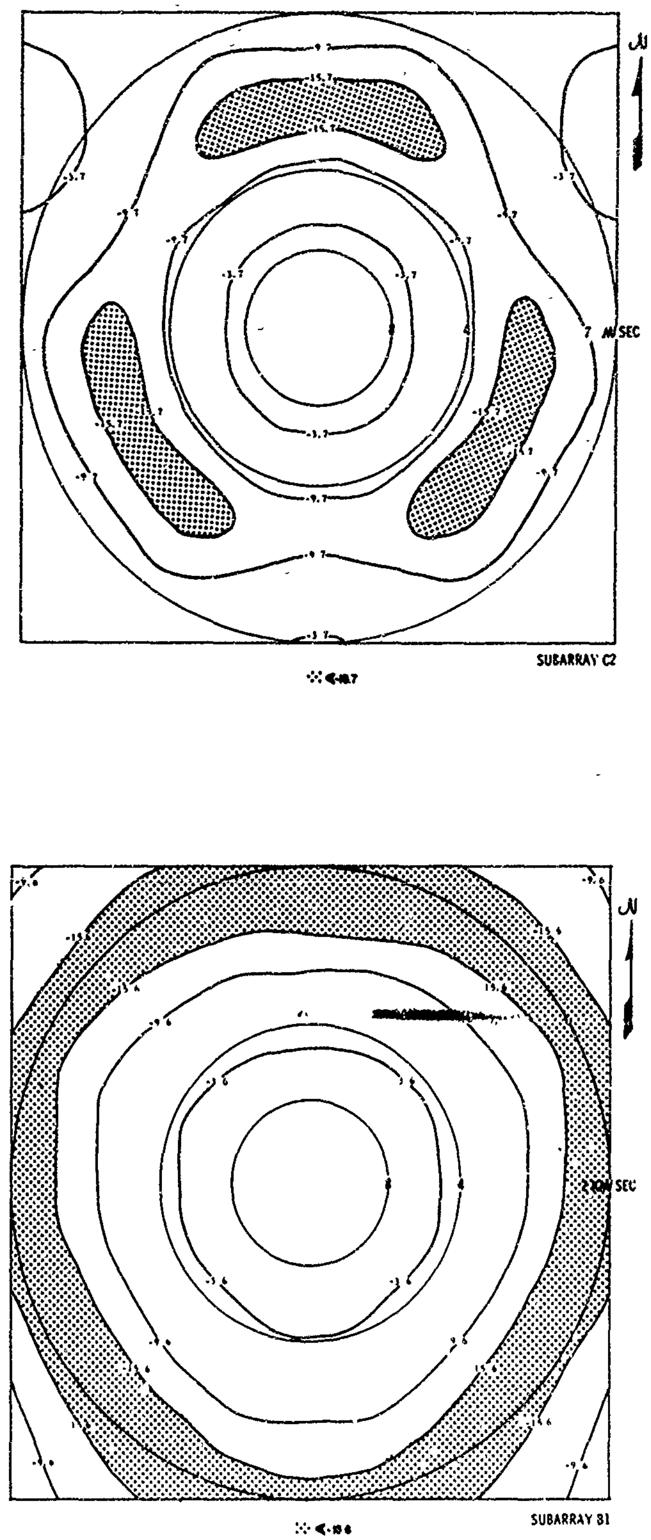


Figure V-2. Wavenumber Response of Measured-Noise Filter at 0.3 cps

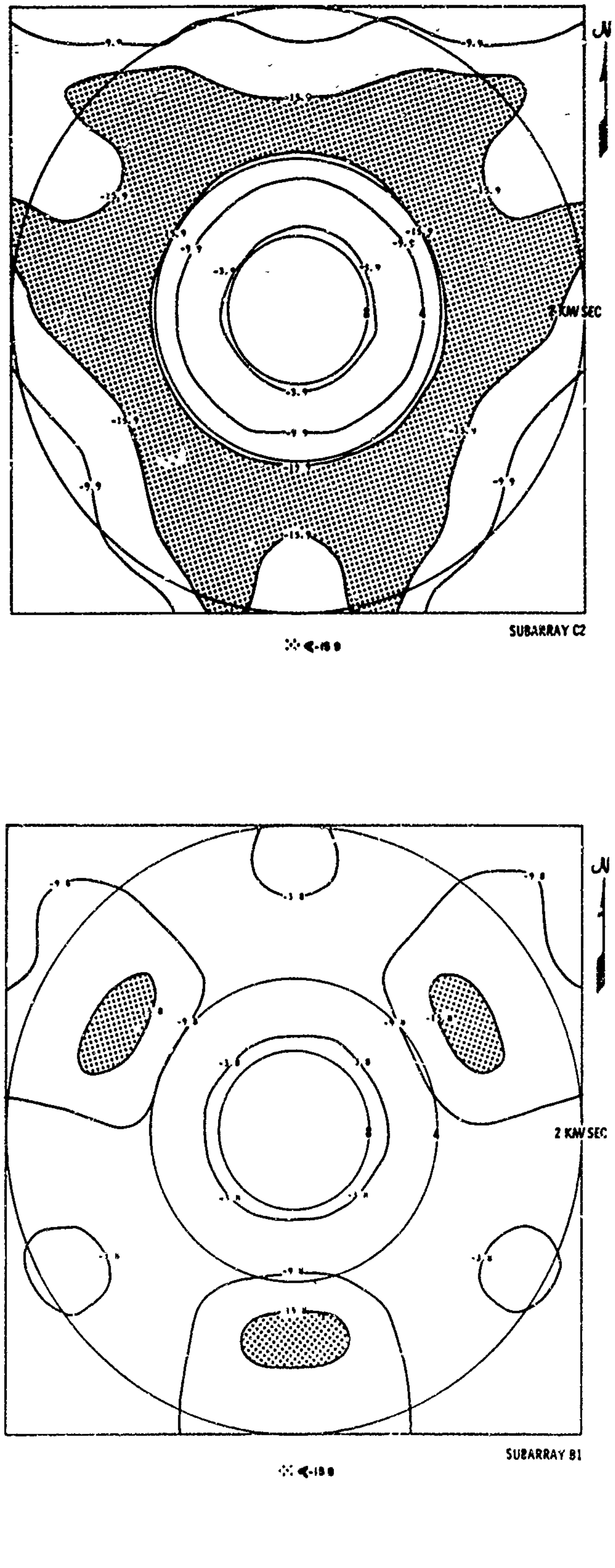
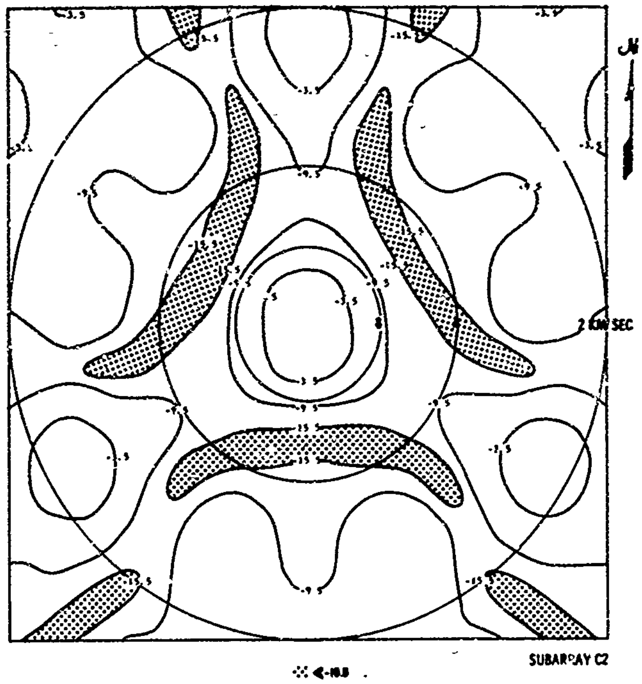


Figure V-3. Wavenumber Response of Measured-Noise Filter at 0.5 cps



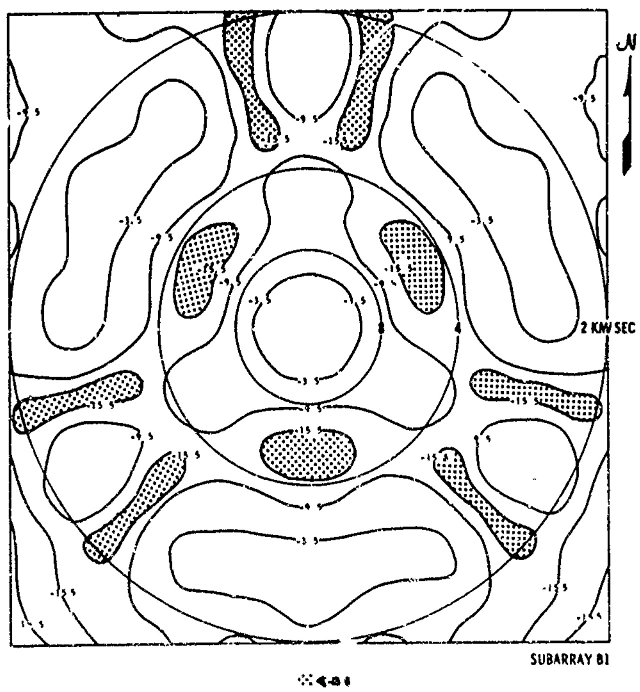
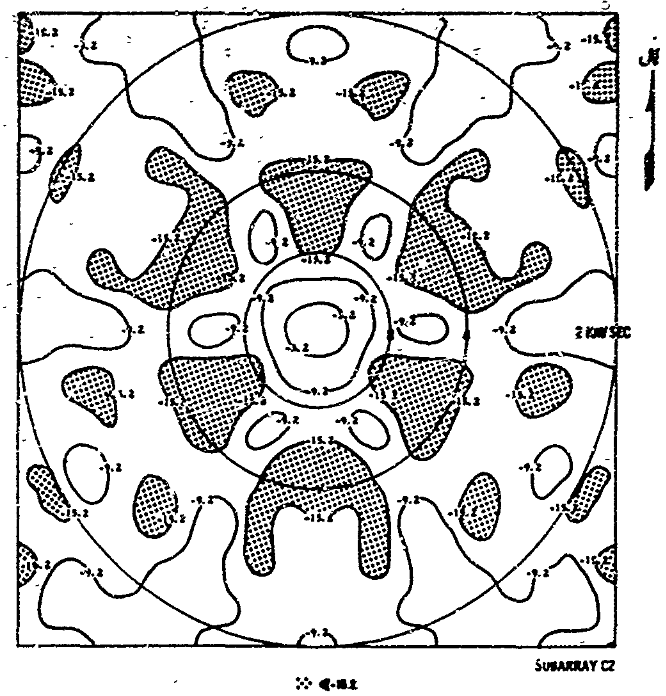


Figure V-4. Wavenumber Response of Measured-Noise Filter at 1.0 cps



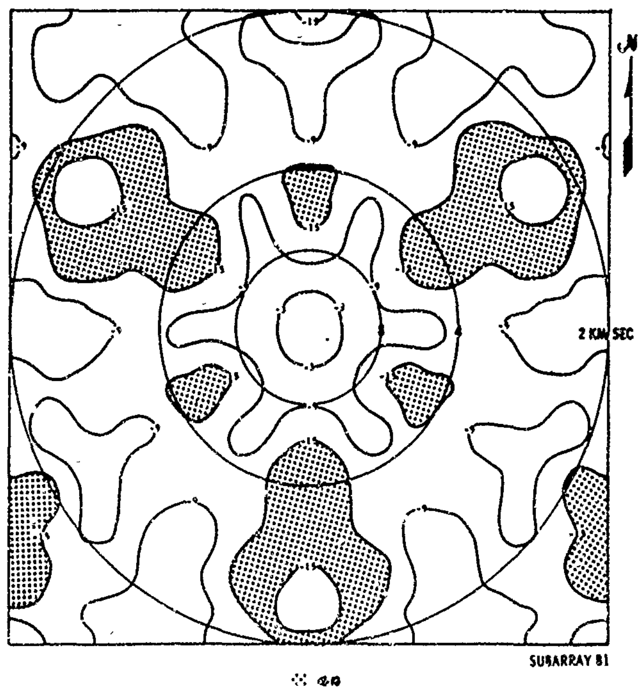


Figure V-5. Wavenumber Response of Measured-Noise Filter at 2.0 cps

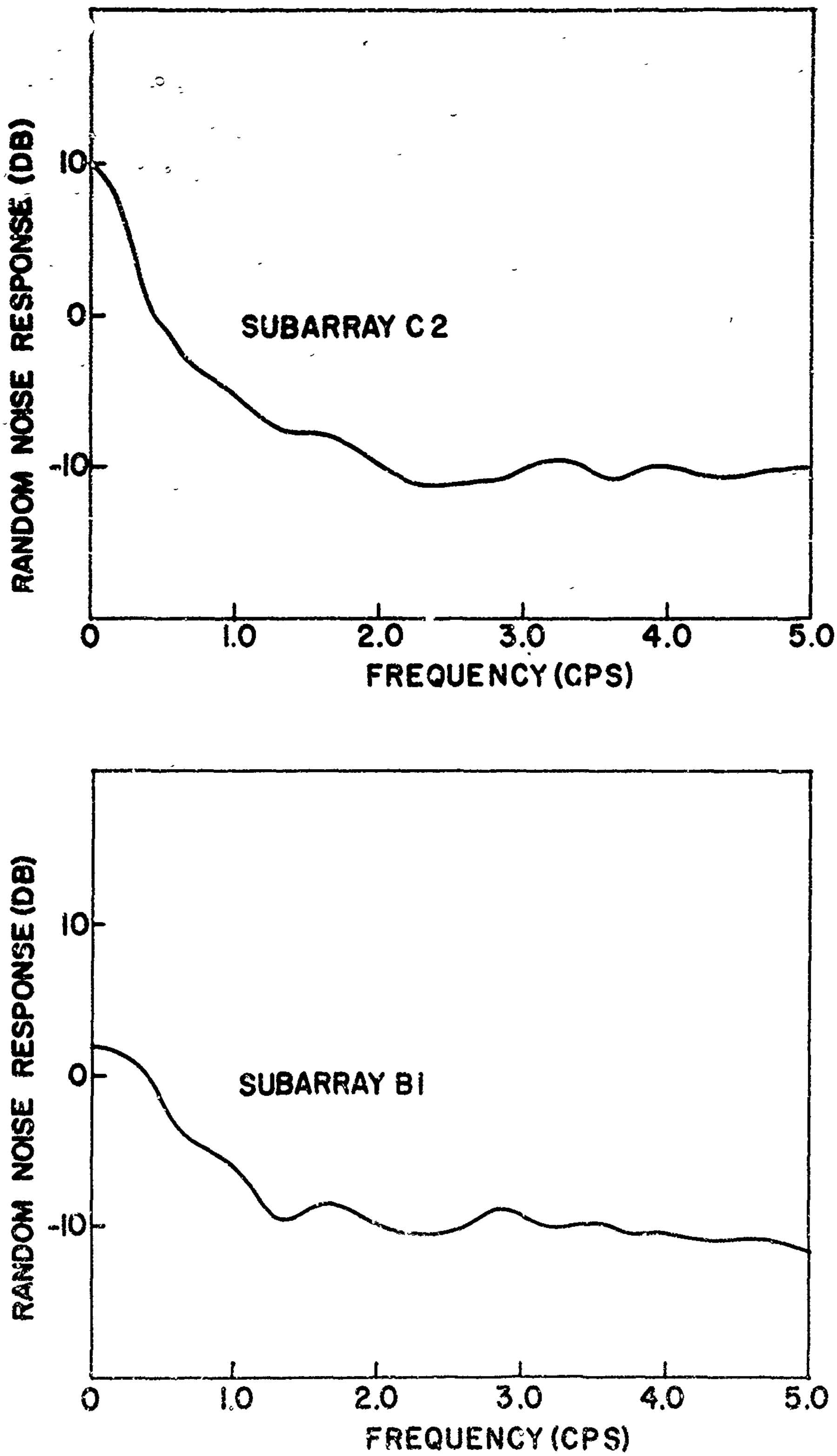
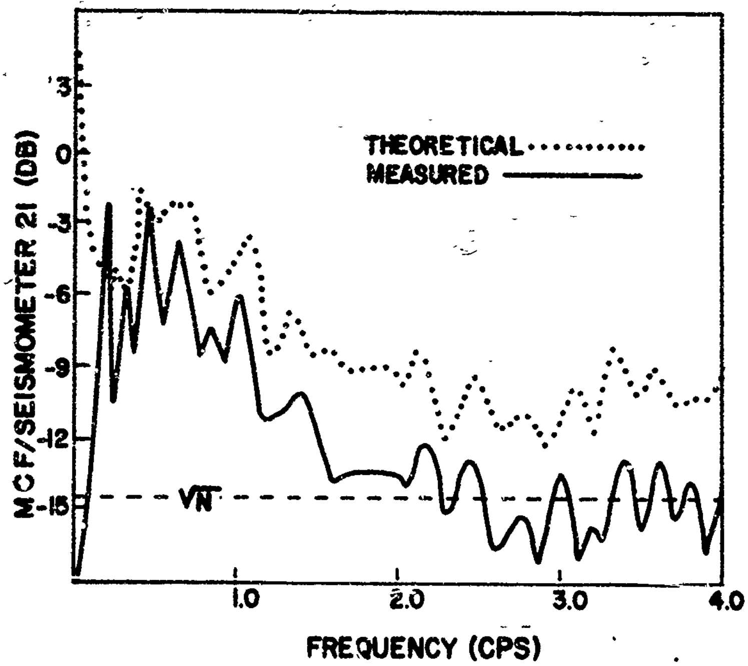
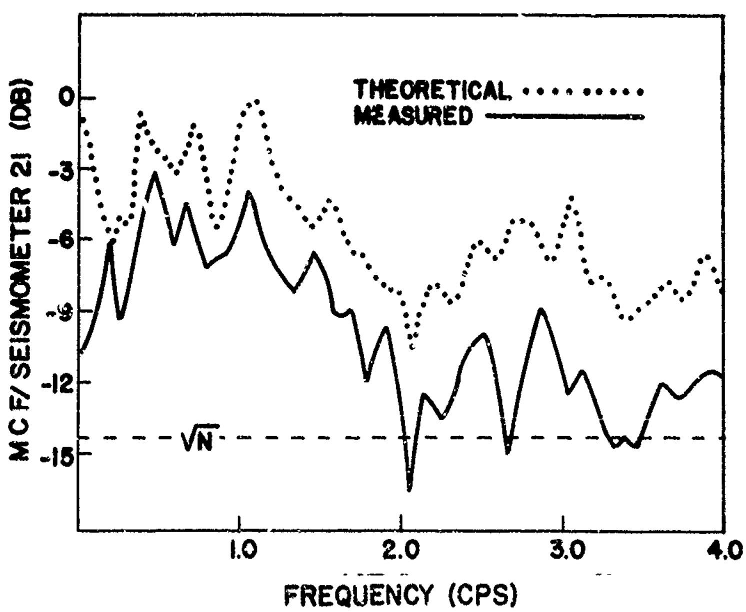


Figure V-6. Random-Noise Response of Measured-Noise Filters



C 2



B I

Figure V-7. Comparison of Noise Fejections Obtained by Theoretical and Measured MCF Systems

SECTION VI

COMPARISON OF MAXIMUM-LIKELIHOOD FILTERS WITH THE THEORETICAL WIENER FILTER

Flinn, et al* evaluated maximum-likelihood filtering at the subarray level for two events. The data were first bandlimited using a filter with response as shown in Figure VI-1. Playbacks of filtered single-seismometer outputs (shown in Flinn's report) indicate that the region of significant noise power was about 0.3 to 3.0 cps after bandlimiting.

Using a 150-sec segment of noise just preceding the signal, Flinn designed maximum-likelihood filters for each subarray for both events. The filters were applied to the noise and signal and to an adjacent noise segment. Signal-to-noise ratios on the maximum-likelihood outputs were computed for both noise segments (i.e., inside and outside the design gate). Their signal measurement was one-half the maximum peak-to-trough amplitude in the first three cycles of the P arrival; their noise measurement was the RMS value over the noise segments. The signal-to-noise ratios were compared with those obtained on a filtered single-seismometer output to determine the signal-to-noise improvement attained by maximum-likelihood filtering. Table VI-1 lists the average signal-to-noise improvement obtained both inside and outside the design gate for the two noise samples.

*Flinn, E. A., R. A. Hartenberger and D. W. McCowan, 1966: Two Examples of Maximum Likelihood Filtering of LASA Seismograms, Seismic Data Laboratory Report No. 148, 8 June.

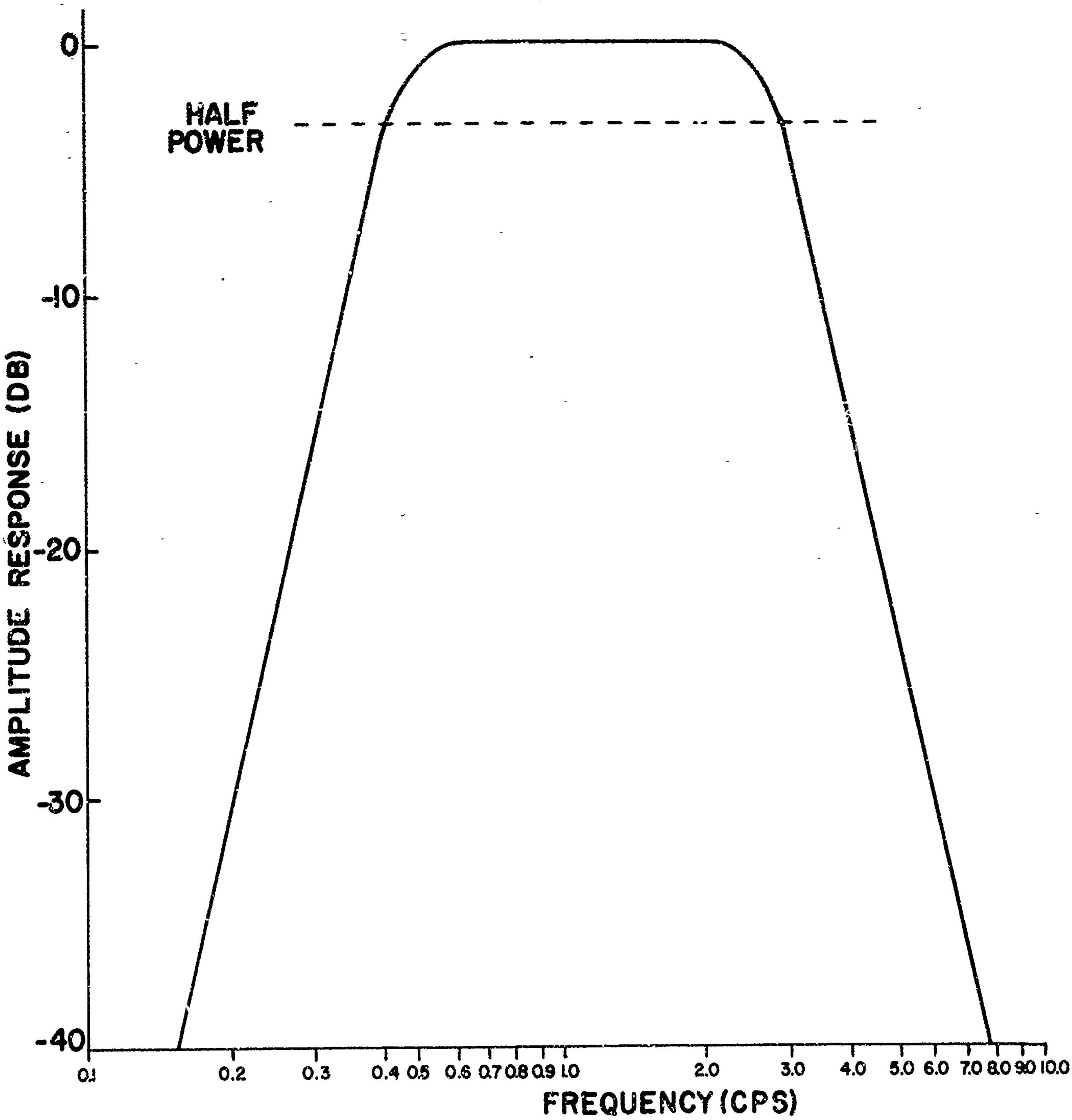


Figure VI-1. Amplitude Response of Bandpass Filter Used by Flinn, et al

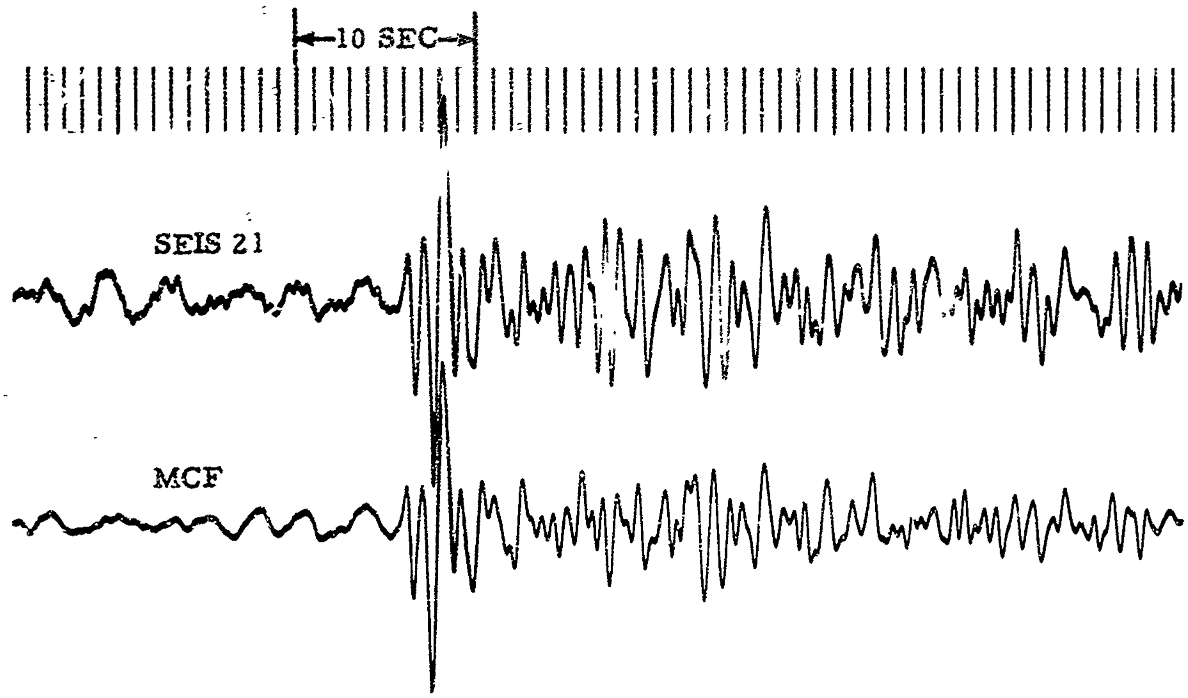
Table VI-1
RESULTS OF MAXIMUM-LIKELIHOOD FILTERING AT THE SUBARRAY LEVEL*

Average S/N Improvement of All Subarrays (db)	10 November 1965		25 November 1965	
	Realizable Filter	Symmetric Filter	Realizable Filter	Symmetric Filter
Inside design gate	9.5	10.8	9.0	11.0
Outside design gate	6.5	6.5	5.5	7.0

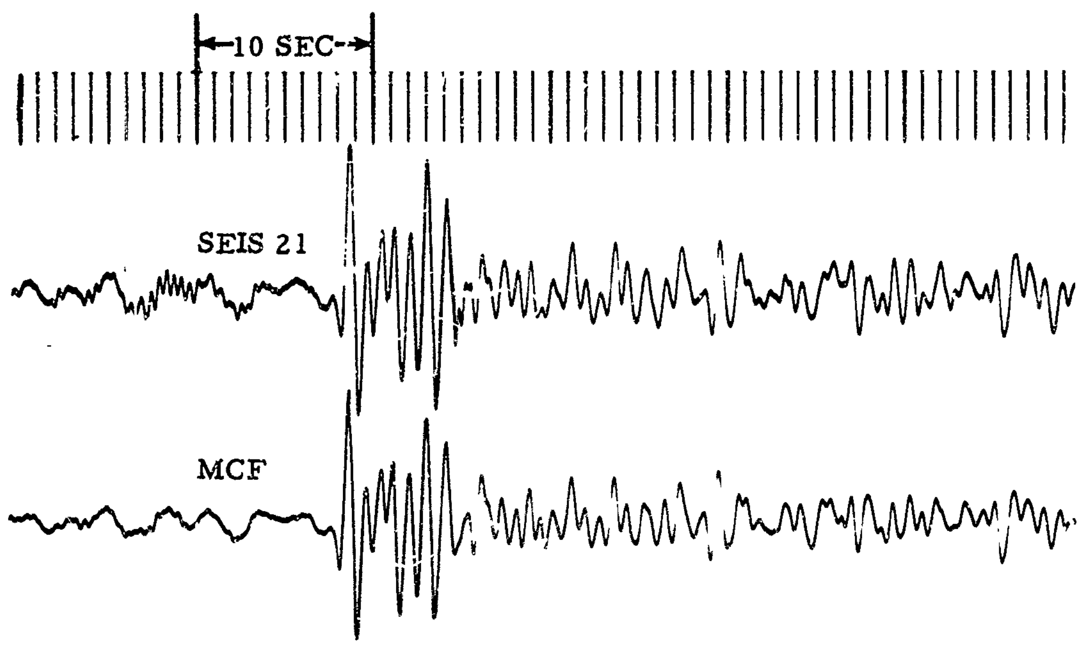
Flinn also states that the signal degradation at the subarray level was small, so improvement values he gives are essentially a measure of the noise reduction in the 0.3- to 3.0-cps band. Figure VI-2 (and the wavenumber responses shown in Section III) show that the theoretical Wiener filter also gave little signal degradation; therefore, its performance can be compared with that of the maximum-likelihood filters by examining the noise reduction in the 0.3- to 3.0-cps band.

To compare the performance of the two types of filters, the 10 November 1965 noise sample (3) was chosen because it covered the noise segment used in the design of the maximum-likelihood filters. Figure VI-3 shows the MCF/seis 21 spectral ratios for four subarrays. In the 0.3- to 3.0-cps band, the ratios vary, but the averages are about 5 to 6 db. (Noise rejection for the other 13 noise samples was about the same.) These values are similar to those achieved by the maximum-likelihood filters outside the design gate. Note also that the noise rejection achieved by the measured-noise Wiener filters was almost equal to that for the maximum-likelihood filters inside the design gate. Thus, it appears that the Wiener and maximum-likelihood filters had roughly equivalent performances.

*Ibid.



SUBARRAY A0 PANAMA EVENT



SUBARRAY A0 GREECE EVENT

Figure VI-2. Signal Degradation of Theoretical Processor

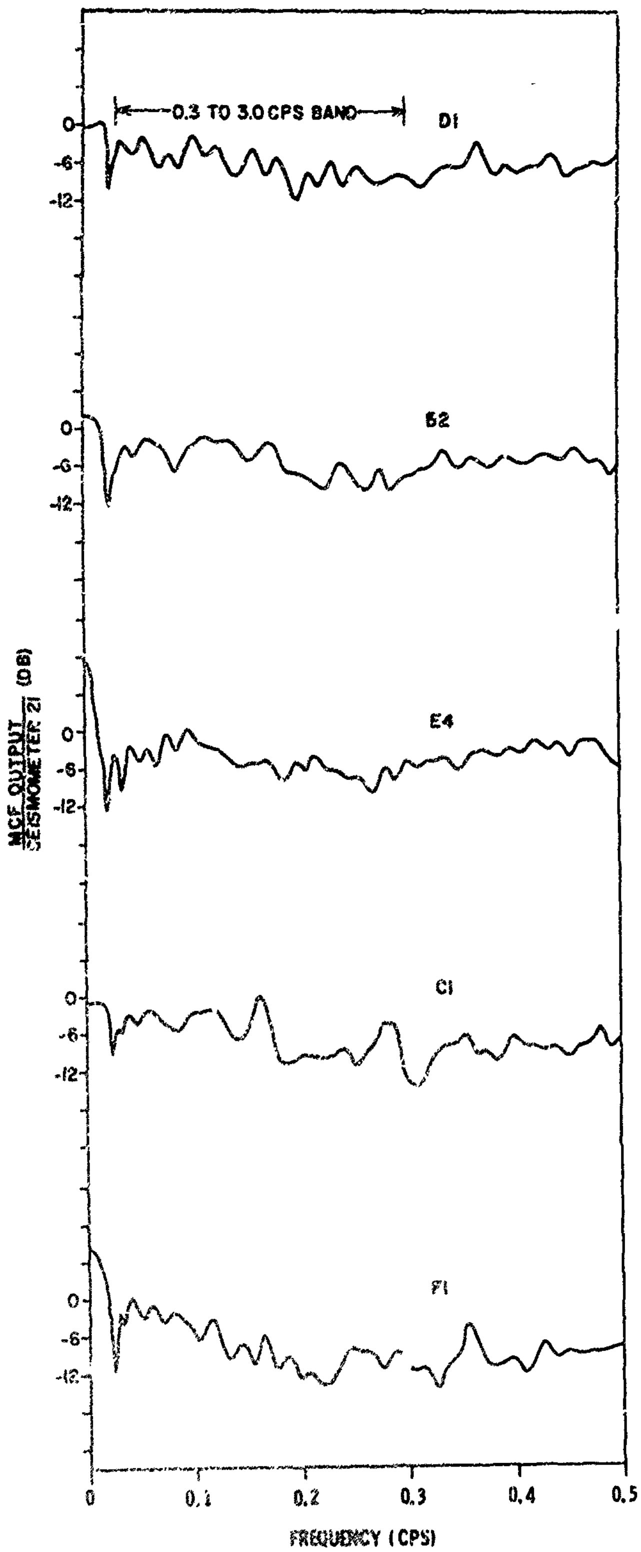


Figure VI-3. Noise Rejection of Theoretical MCF at Four Subarrays, Noise Sample 3

It should be noted, however, that a precise comparison would require applying the two types of filters to the same noise samples and using the same techniques to evaluate their performances. The format of the data used in this evaluation would have made such a comparison quite expensive; and, in view of the work previously done,* the simpler comparison first discussed was preferred.

---

*Texas Instruments Incorporated, 1965: A Comparison of Wiener and Maximum Likelihood Multichannel Filtering, Summer Development Rpt. by D. Jackson, 23 Oct.

SECTION VII
NOISE ANALYSIS

To study the properties of the noise field at the subarray level, noise sample 14 was analyzed at subarrays B1 and C2. The analysis consisted of estimating the predictability as a function of frequency and comparing the absolute noise level at LASA with that at TFO.

A. NOISE PREDICTABILITY

To estimate the noise predictability, the data were first approximately whitened using a short (1.0-sec) deconvolution filter designed from the center seismometer. Then, a 7-channel, ring-stacked filter was designed to predict the center-seismometer output from the other 24 seismometer outputs. The filter was 3.4 sec long and was designed from a 480-sec gate for both subarrays. Figure VII-1 shows the fractional prediction error as a function of frequency. At both subarrays, the noise was over 99 percent predictable at the microseismic peak (0.25 cps). At 1.0 cps, the predictability was still about 65 percent; and above 2.0 cps, the noise was essentially unpredictable.

Typical prediction curves for TFO, CPO, and WMO are shown in Figure VII-2. The noise predictability at the two LASA subarrays was about the same as that obtained at TFO and WMO, but the predictability was markedly superior at CPO. At CPO, three seismometers were about 0.3 km from the center seismometers; however, previous studies indicated that if only that part of the CPO array which did not include the three closely spaced seismometers was used, the noise was still more predictable than at other stations (Figure VII-3).

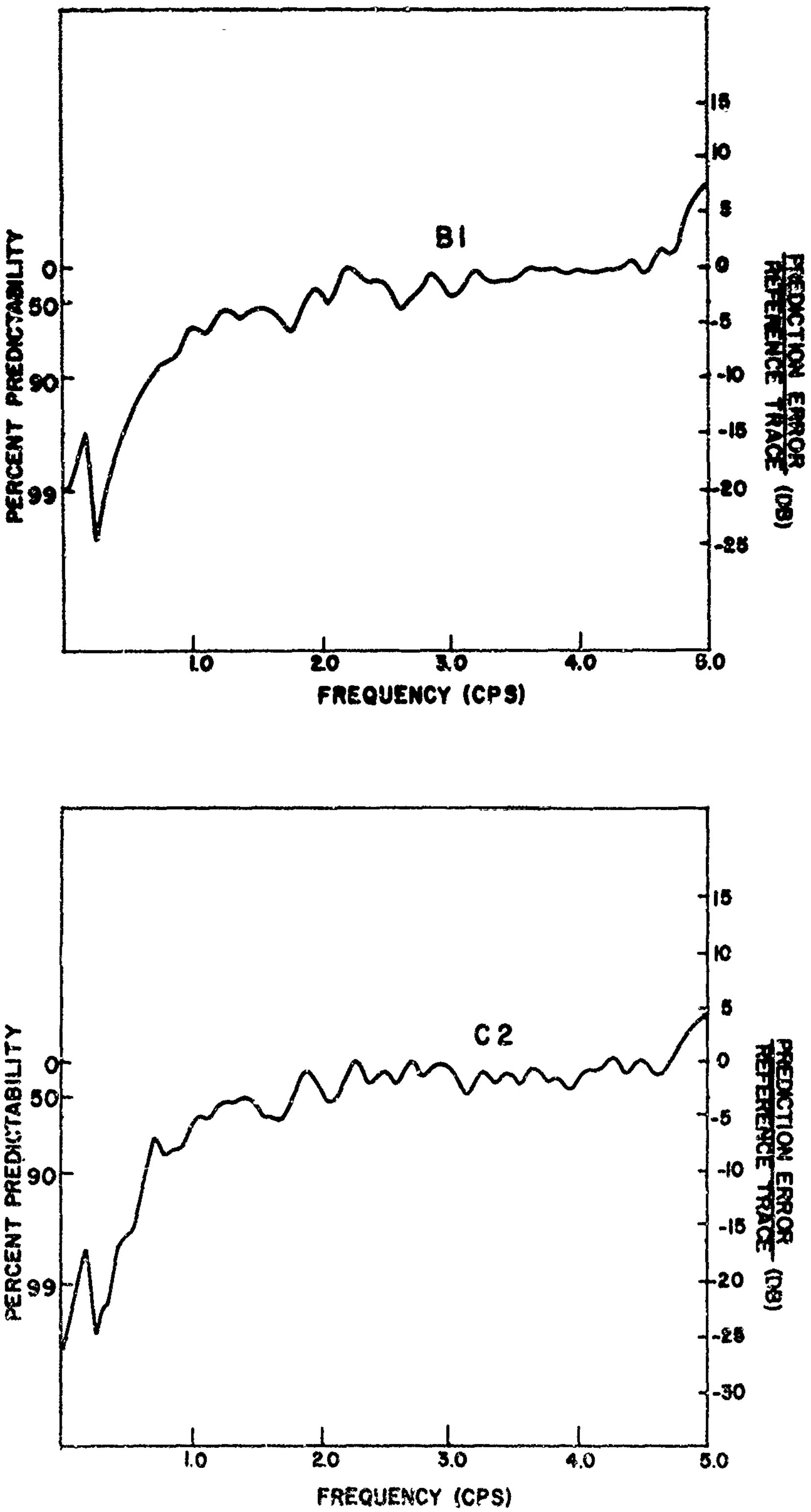


Figure VII-1. Noise Predictability at LASA Subarrays B1 and C2, Noise Sample 14

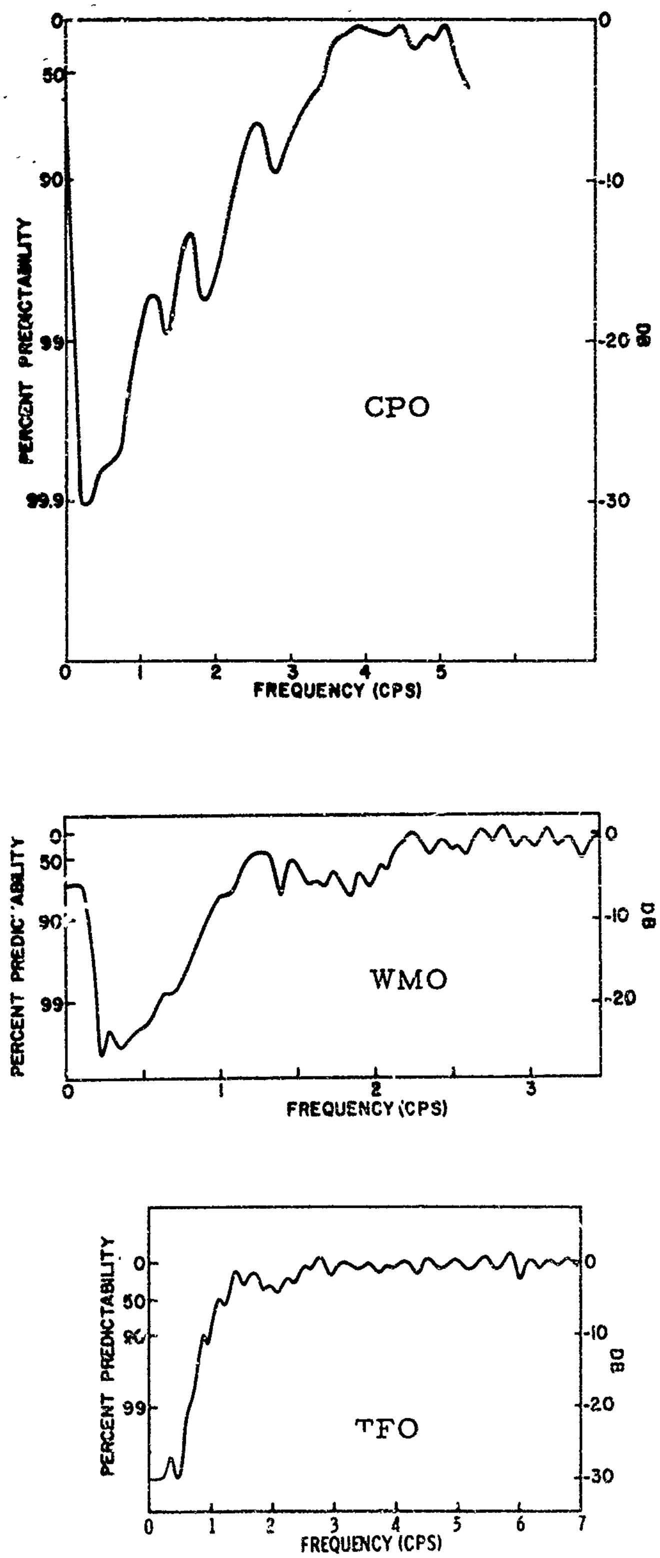


Figure VII-2. Noise Predic:ability at Other Array Stations

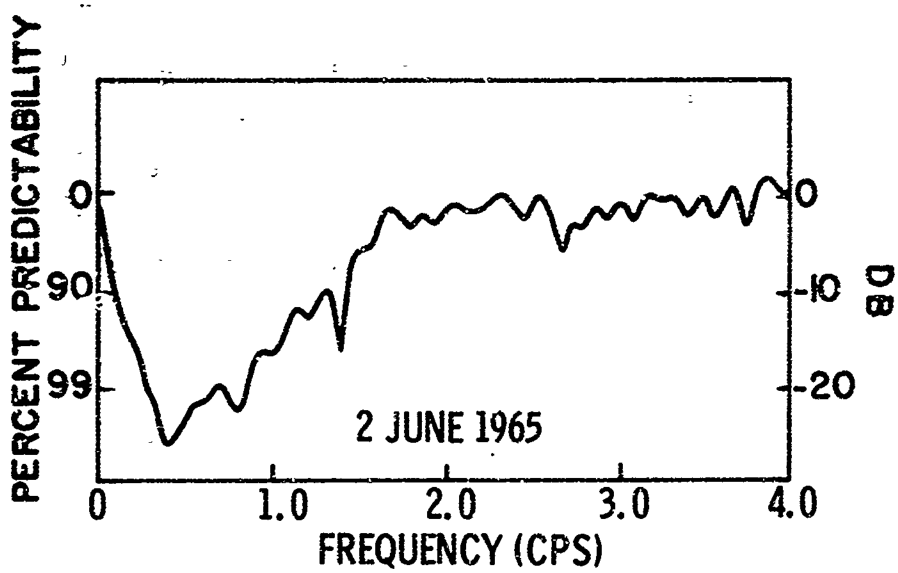


Figure VII-3. Noise Predictability for CPO Partial Array

The prediction filters designed for subarrays B1 and C2 were applied to the 480-sec noise sample immediately following the sample used in the filter design. Figure VII-4 shows the results, which are quite similar except below 0.5 cps, where both B1 and C2 show considerable differences. This suggests that the spatial organization of the low-frequency noise has changed between samples. The sensitivity of prediction filters to changes in the noise field is unknown; however, the apparent short-term instability of the LASA noise field needs further investigation.

B. ABSOLUTE NOISE LEVELS AT LASA

All filter responses except that of the seismometer were removed from the power-density spectrum of seismometer 21, subarray C2. (C2 was considered representative of the average noise level at LASA). Using the 1.0-cps calibration data, the spectrum was scaled in absolute units of db relative to 1.0 $(m\mu)^2/cps$ at 1.0 cps and compared to the spectrum obtained for TFO

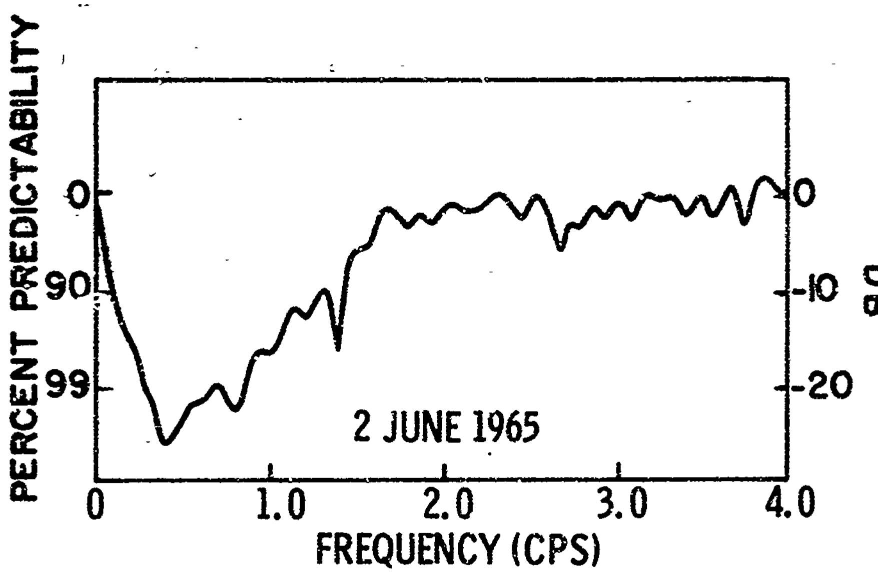
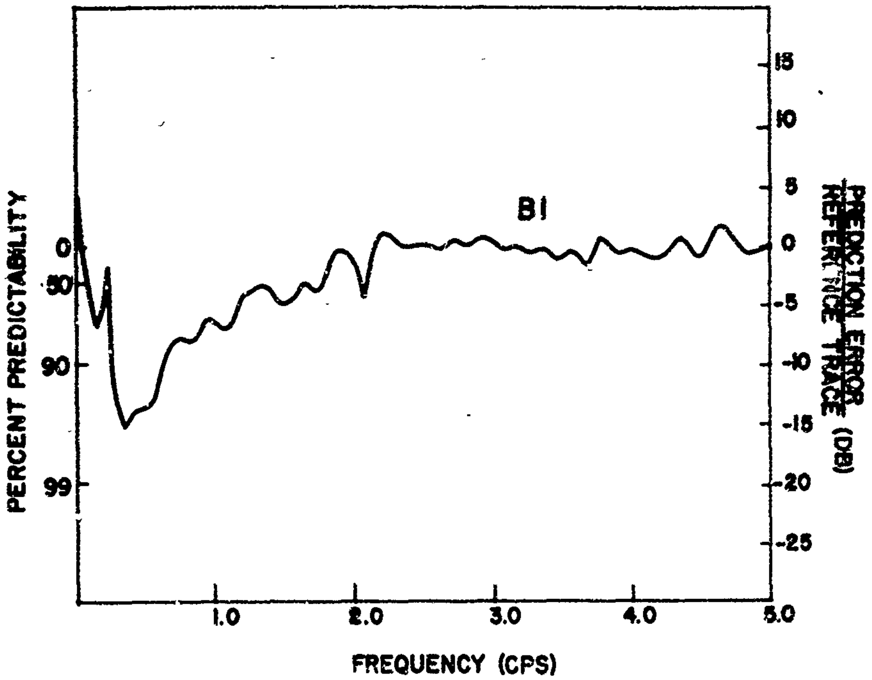


Figure VII-3. Noise Predictability for CPO Partial Array

The prediction filters designed for subarrays B1 and C2 were applied to the 480-sec noise sample immediately following the sample used in the filter design. Figure VII-4 shows the results, which are quite similar except below 0.5 cps, where both B1 and C2 show considerable differences. This suggests that the spatial organization of the low-frequency noise has changed between samples. The sensitivity of prediction filters to changes in the noise field is unknown; however, the apparent short-term instability of the LASA noise field needs further investigation.

B. ABSOLUTE NOISE LEVELS AT LASA

All filter responses except that of the seismometer were removed from the power-density spectrum of seismometer 21, subarray C2. (C2 was considered representative of the average noise level at LASA). Using the 1.0-cps calibration data, the spectrum was scaled in absolute units of db relative to 1.0 $(m\mu)^2$/cps at 1.0 cps and compared to the spectrum obtained for TFO



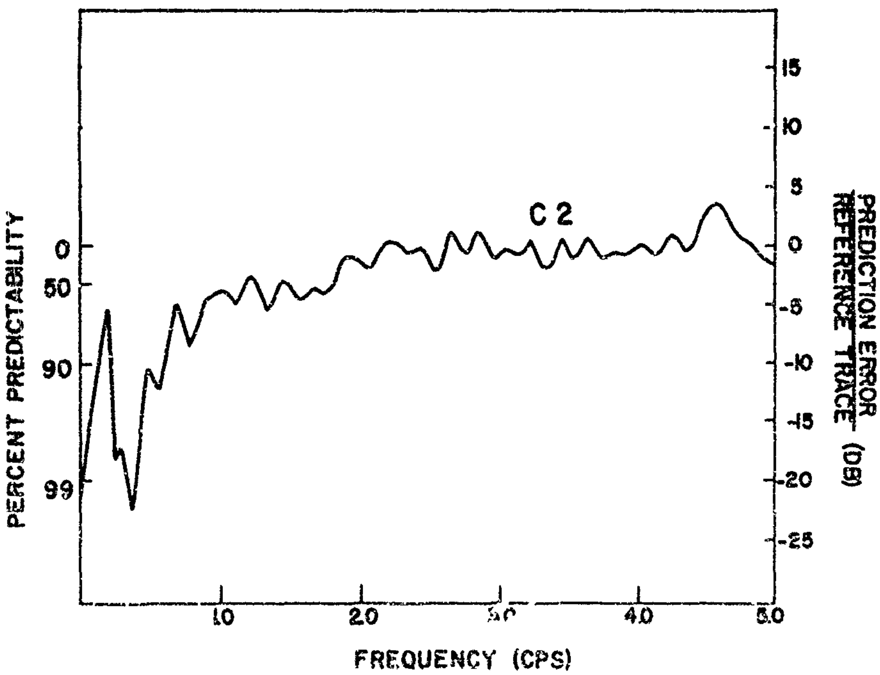


Figure VII-4. Noise Predictability at LASA Subarrays B1 and C2 for Noise Sample Immediately Following Noise Sample 14

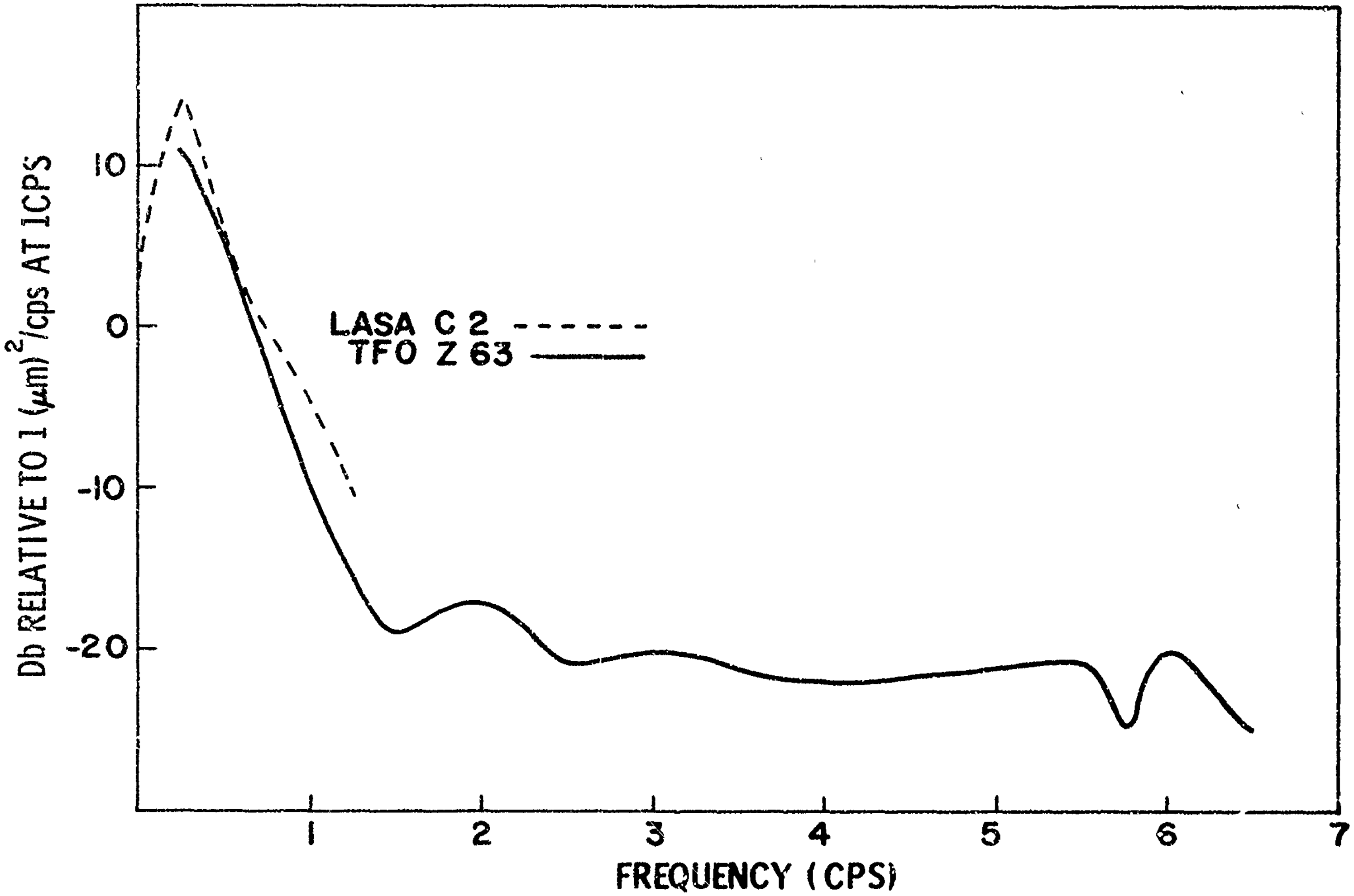


Figure VII-5. Comparison of Absolute Noise Levels at LASA and TFO

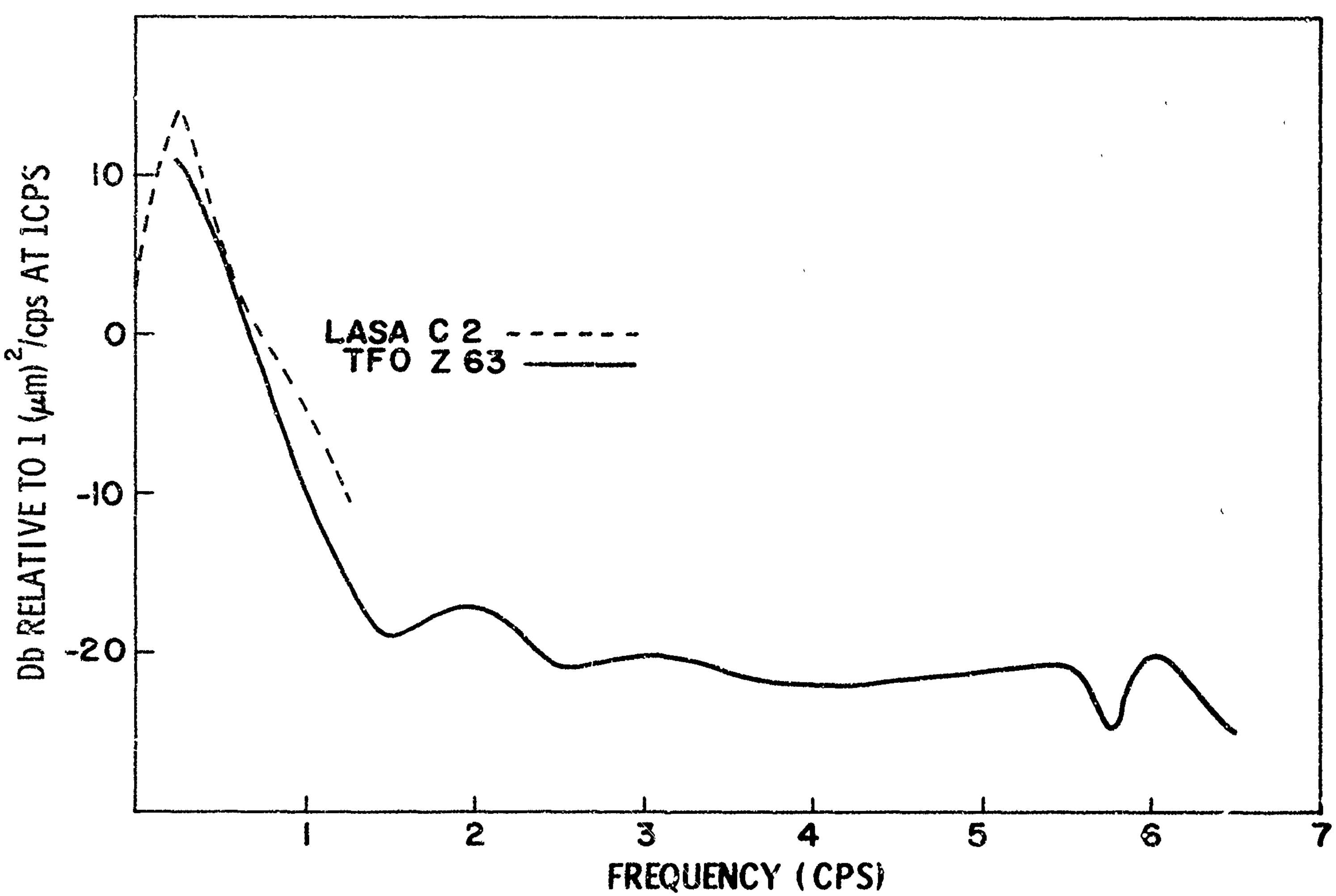


Figure VII-5. Comparison of Absolute Noise Levels at LASA and TFO

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Texas Instruments Incorporated Science Services Division P.O. Box 5621, Dallas, Texas 75222	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

LARGE-ARRAY SIGNAL AND NOISE ANALYSIS - SPECIAL SCIENTIFIC REPORT NO. 3 - SUBARRAY PROCESSING

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Special Scientific

5. AUTHOR(S) (Last name, first name, initial)

Harley, Terence W.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
16 October 1967	43	4

8a. CONTRACT OR GRANT NO. Contract No. AF 33(657)-16678	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. AFTAC Project No. VT/6707	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. AVAILABILITY/LIMITATION NOTICES

This document is subject to special export controls, and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Chief, AFTAC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
ARPA Order No. 599	Air Force Technical Applications Center VELA Seismological Center Headquarters, USAF, Washington, D.C.

13. ABSTRACT

A theoretical Wiener multichannel filter was designed and applied to all operating subarrays for 14 noise samples and three signals. The filter system chosen had a disk signal model (11 km/sec to infinite velocity) and a noise annulus (2 to 6 km/sec) and exhibited good wavenumber response to 0.2 cps. Preliminary analysis showed that it was necessary to equalize the noise at the low-frequency peak (0.2 to 0.3 cps) prior to processing to obtain consistent noise rejection at low frequency. Because of the peaked spectrum, equalization could be accomplished by adjusting the 25 channels in a subarray to have the same RMS noise level (i.e., 1-point equalization). Two measured-noise Wiener filters were designed using an infinite-velocity signal model (with 30-percent gain fluctuation added). Their noise rejection was about 2 db better than the theoretical system over most of the 0- to 5-cps band. The theoretical Wiener filter performed about as well as the maximum-likelihood filter that had been applied to a noise sample not used in its filter design. The measured-noise Wiener filter performed almost as well as the maximum-likelihood filter that had been applied to the noise sample from which it was designed. Within a subarray, the noise at LASA was more than 99-percent predictable at the microseismic peak (0.2 to 0.3 cps). At 1.0 cps, the noise was still 65-percent predictable; but above 2.0 cps, it was essentially unpredictable. These results are similar to those at TFO and WMO but significantly lower than at CPO. The absolute noise level on seismometer 21 of subarray C2 (which was close to the average LASA noise level) was between 0 and 6 db higher than that at TFO in the 0- to 1.5-cps band. However, variations in noise level larger than 6 db were observed across LASA.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Large-array signal and noise analysis Subarray processing Theoretical Wiener multichannel filter Measured-noise Wiener filters Maximum-likelihood filters						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Unclassified

Security Classification